# 6. MEASURING FOOD CONSUMPTION IN EPIDEMIOLOGIC STUDIES

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The most important in nutritional epidemiology are:

1. Estimation of adequacy of the dietary intake in different population groups.
2. Investigation of the relationship between diet and health outcomes.
3. Evaluation of nutritional interventions and educational programs.

If an association is observed in an epidemiologic study, we are usually concerned whether it represents a true cause-effect relationship. Factors that are considered as criteria for causality are: strength of association, the consistency of findings in different studies and populations, the presence of dose-response gradient, the appropriate temporal relationship, the biologic plausibility, and coherence with existing data (1, 2, 3).

In the field of nutritional epidemiology associations are not likely to be strong – although weak associations in dietary studies may have large public health effect if the dietary factor is common and the disease presents an important public health concern (2, 4). Criterion of strength of association is more likely to be problematic in nutrition studies due to the frequent occurrence of measurement error. Dose-response relationships are likely to be non-linear – because both too small and too high level of dietary exposure can be harmful. Evaluation of consistency in nutritional studies is a challenge. There is a problem with consistency across the studies because of incomparability of dietary instruments used and different cutpoints in different populations (3, 5). In a study of diet and disease failure to observe statistically significant association, when it really exists, can occur in several circumstances:

1. Variation in diet is insufficient to observe relationship.
2. Method of measuring dietary intake is not sufficiently precise to measure small differences that truly exist.
3. Association can be missed because of small statistical power.
4. Relationship can be undetected because the temporal relationship did not encompass the true latency period.
5. Association can be undetected because some unmeasured third variable was related to exposure and the disease in opposite direction.
6. Methodological sources of bias could obscure a relationship.

Although comparability of findings with the established mechanism of disease causation supports causality, *post hoc* biologic explanations should be viewed continuously because they are mostly developed for most observations (6, 7).

For the nutritional studies, the most complex issue is how to measure the relevant exposure based on the consideration of four aspects of study design: study type, time period, point of measurement and type of the measurement. The study question and study design suitable to answer that question will have an impact on choice of the best method to measure exposure (7). Imprecise or inaccurate measurement can lead to surprising and unreliable results.

There are various methods of assessment of food consumption and nutrients intake and the choice of proper one depends mainly on the aim of the study (8).

## Measurements on the household level

To assess food or nutrient intakes at the household level one of following methods can be used (1, 2, 9):

1. *Food account method (Household budget surveys = HBS)* – the main respondent or the interviewer keeps a detailed record of the quantities of food entering the household including all sources. The method assumes that within a given category of households, there is no change in average levels of food stocks, although it is recognized that some households will acquire more foods than they consume over the study period, and others acquire less and use existing stocks. Especially, effort is made to estimate the proportion of diet consumed from the outside the household food supply (restaurants, bars, etc.). The nutrient content can be assessed by using appropriate food composition tables – preparation and waste losses are also estimated. The principal strength of the HBS data is their availability and continuity (if conducted personally). They are accessible and cheap for analyzing food and nutrient consumption trends in epidemiologic studies.
2. *Inventory method* – this method is similar to the HBS – because respondents are asked to keep records of all foods coming into the house. In addition, the larder inventory is carried out at the beginning and at the end of the study period. The main advantage of this method in comparison to HBS is that it provides information about direct amount of foods available for consumption within a household.
3. *Household record* – in this method all foods available for consumption (raw or processed) are weighted or estimated in the household measures before meals. Any food consumed by visitors is subtracted from the total.
4. *List-recall method* – structured survey in which the respondent is asked to recall the amount and cost of food obtained for household use over a given period. It can be used to provide an estimate of food costs, and net household consumption of both foods and nutrients. This method is good for population in which most foods are purchased rather than home-prepared. It is relatively easy and cheap because it requires only one interview.

Household surveys provide powerful tool for obtaining information about food consumption characteristic of wide population groups. In most instances data have already been collected at the expense of government or other agencies – so costs are lower.

## Measurements at the individual level

Nutritional epidemiology provides the only direct approach to the assessment of relationship between diet and risk of most chronic diseases. The majority of nutritional epidemiologic studies require detailed information on the actual and past diet and nutrient intake from the large number of subjects. The choice of prospective or retrospective methods is determined by the study design and by available resources, respondents' skills, etc. All methods depend on the ability of respondent to provide accurate information. It is therefore important currently used to establish validity of responses in the specific study sample.

There are different methods used to assess actual diet (1, 2, 9):

1. *Food Frequency Questionnaire (FFQ)* – Out of all methods, FFQs are most frequently used in cohort studies. They are designed to assess usual eating habits, over recent months or years, and comprise a list of foods most informative about the nutrient or foods of interest. The number of items (categories) varies in different studies from several to assess single nutrient up to hundreds for assessment of variety of nutrients. Questionnaires generally concentrate on frequency of specific portion of food consumed and quantities. Major principles of FFQ design are:
   - The purpose of questionnaire has to be clearly defined.
   - Number of foods included should be minimized and cover those that are main sources of nutrient for the majority of subjects.
   - Questions about frequency and portion size should be close rather than open.
   - Frequency categories should always be continuous.
   - Portion sizes should reflect known consumption patterns in the population.
   - Aids to the assessment of portion size are desirable in the form of photographs, drawings, etc.

   The main advantages of the FFQ are uniformity of administration and low costs. Primary disadvantages are the amount of work required for preparation, validation and imprecision of the estimates of usual food consumption or nutrient intake.
2. *Diet history* – is usually included in the interview that provide detailed information on food consumed usually, portion size, recipes, and frequency of food consumption over the recent past. This method is less commonly used in the epidemiologic studies because of the necessity of face-to-face interviews, but it is most frequently used by the clinical dietitian.
3. *24-hour recall* – This method is based on in-depth interview conducted by a trained interviewer. The interviewer solicits detailed information on food and drinks consumed during the previous day (24 hours). The adequacy of dietary data depends on short-term memory. Detailed information about food preparation method and recipe ingredients, brand name identification of commercial products is required. Accurate identification of portion size is critical for data collection. 24-hour recall is based on actual intake – may be used to assess the absolute amount of energy rather than relative energy and nutrient intake. When one uses open-ended method – respondent can recall any food or food combination. So, they allow for different types of the food, food source, food processing methods, and food preparation. Thus it is good for culturally diverse populations representing variety of foods and food habits. This

method does not require respondent's literacy. If the purpose of the study requires estimation the distribution of individual intakes within the group it is necessary to collect more than one recall.

4. *Dietary Records* – In this method subject are taught to describe and give an estimate of weight of food directly before eating, and to record any leftovers. Records are generally written by respondents, sometimes verbal records with description recorded on tape cassettes have been obtained. When sufficient number of days is collected to obtain the usual intake, this method is often used as a "standard" method to assess validity of individual intake of nutrients for other instruments.
5. *Checklist* – allows avoiding problems with estimation of the frequency of food consumption one can find in FFQ. The checklist is a printed list of foods commonly eaten in the population. At the end of each day respondent marks the foods eaten at this list, sometimes also the number of standard portion is marked.

## Servings vs. portions

To quantify food groups intake, and then calculate nutrient intake, measurements of servings, standard portions or grams have been used. Recommendations to the public traditionally have been given in the form of servings (9, 10). Food group intake as an exposure in the analysis of disease risk is usually quantified as grams per day. The last approach does not differentiate nutrient profiles of foods and beverages included in the same group (e.g., milk and cheese in the dairy group).

Researchers working with dietary data have to make decision how to express the amount of foods eaten. In the standard FFQ (number of servings) is recorded. However, during one serving respondent can have different portion size – small, medium, big, etc. – which is considered as one serving (11). There are different approaches to this problem. Some researchers use standard portion as a unit for one serving, but such "mean" portion can be different at the population level. The other approach is to use semi-quantitative FFQ with a portion size assessment tool. Standard portions, household measures, food models and food pictures are used as aids for quantitative estimation of food items in dietary data collection. In some questionnaires respondents are allowed to choose their portion size between a few predefined portions (e.g., small, medium or big – from the picture), sometimes – they can multiply the previously specified portion (e.g., teaspoon, cup, etc.) and sometimes they can define the portion size by themselves (12). All these methods have impact on validity of dietary data and that should be defined before using a chosen instrument. Cade et al. (12) in the review of papers on validity of food-frequency questionnaires published in 1980–1999 found that 22% of them did not provide portion size information, 42% used specified portion size, and 36% allowed participants to describe their own portion size. The authors found that the agreement between FFQs and reference dietary recall were highest when respondents were able to describe their own portion size (correlation: 0.5–0.6) compared with portion specified in the questionnaire (correlation: 0.4–0.5) and no portion size specified (standard portion used for nutrients calculation; correlation: 0.2–0.5).

Epidemiologic models that examine relationship between the dietary exposure and the disease rank individual's intake to find statistically significant difference in the risk of disease between higher vs. lower intake. Thus, an important question is whether different measures (e.g., grams vs. number of servings daily vs. number of standard portions daily) rank individuals in the same way. Nothlings et al. (11) analyzing data for 92 887 men and 113 834 women showed that Spearman correlation between intake expressed in grams and servings ranged from 0.84 for grains to 1.00 for poultry and fish. Studies on portion size estimation accuracy showed that it depended on the method of estimation (13, 14).

## Reliability and validity of nutritional data

Reliability refers to consistency of measurements on more than one administration to the same person (15). Because diet of every individual varies on a daily, weekly, and seasonal basis the assessment of reliability depends on the type of measurement used (e.g., FFQ vs. 24-hour recall). If one is interested in "usual" intake, single 24-hour recall will not be accurate (2).

Validity refers to the degree to which the measurement (questionnaire) actually measures the aspect of diet that it was designed to measure.

There is no perfect measure of dietary intake. Thus validation studies never compare the method in question with true intake, rather with another method that is judged to be superior (16). So the crucial for validation process is that the errors of both methods are independent as possible to avoid surprisingly high estimates of validity (17, 18).

The main problem in a validation study is how to define the truth, which is unknown. The truth is usually estimated by reference to another method (relative validity). It describes the agreement between a test measure and reference measures. The assessment of validity should be conducted in the same circumstances as for the main study and should be carried out each time the new study in the new population or setting will be set up. It is important to establish a priori how the results of the validation study will be interpreted and used in the main study (2). The main issue of validation is to assess what level of agreement is good enough to reduce the measurement error to the acceptable one (19). A particular concern is whether those who misreport their intake are different in other characteristics from those who do not. Some researchers suggest, for example, that overweight people tend to under-report their fat intake (20).

The major aspects of validation of dietary recalls or food records are:

1. How accurately individuals can record or recall their intakes on a given day in term of food identification and portion size estimation.
2. How precise the food composition tables (databases) and coding systems used are.
3. How well selected days represent usual individual intake.

Some researchers made an attempt to assess accuracy of reporting by comparison with direct observation of respondents. Agreement of foods on item basis can be estimated as 70%–80%, and especially omissions are more frequent than additions. Respondents tend to omit less frequently consumed foods and those foods, which were added to the main meal (2).

Studies looking for differences in the portion size estimation have found that certain types of foods are more likely to be overestimated than others.

Reported differences in mean energy intake calculated from 24-hour recalls compared with observations range from no significant difference to 19% less in recalled intakes. A 24-hour recall tends to underestimate energy intake by about 10% compared with observed intake. In general, those who consume less than average are more likely to overreport the energy intake, while those who eat more than average tend to underreport (flat slope syndrome) (2). The interpretation of the results of these studies may be difficult. Most of them are conducted in the institutional settings – so the generalization of their results to the general population would be problematic.

An alternative approach to assessing the accuracy of reported intakes is to ask the respondents to collect duplicate portions of all foods consumed. Then investigator carefully identifies all foods and their weights and then compares them with recalls. This procedure is much more time and effort consuming. In addition, respondents are more conscious of what they are eating when they prepare duplicate portions, so they may record they intakes more accurately.

Most often researchers decide to use FFQ or 24-hour recall methods. Most validation studies compare results derived from FFQ to intake assessed based on multiple days from 24-hour recall or records. More recently biomarkers or energy expenditure measures have been used as a reference method.

Because each, even subtle, change in the design of instrument can affect their performance – each instrument should be evaluated separately.

## Measurement error in dietary assessment

In planning the study it is very important to consider any potential errors that can occur later on. Two most important types of errors: sample bias and measurement bias. The first one is just improper selection of the study sample. In this case the results cannot be extrapolated to the general population. Measurement error can occur during the assessment of exposure or health outcome. It can have several sources like tools and procedures used in the study or observer itself. If we use interview/recall method in the study the error maybe due to interviewer, respondent, and the method.

One of the important sources of error in the interview method is the interviewer bias, the second one respondent bias. The errors arise from the assessment of frequency of food consumption, portion size estimation, daily variation and failure to report usual diet. Especially important is that the reliability of our data depends on subject's memory – so closer time period to recall more valid information we have (21).

The next problem in the assessment of usual intake is daily variation (22). Individuals do not consume the same food from day to day and substantial error is introduced when diet is assessed from a single day's dietary investigation. Daily variation is one of the main factors reducing precision of individual estimates in records or 24-hour recalls. The variability from the day to day is closely related to the number of nutrients of interest.

Very important aspect of nutritional assessment is portion size assessment. It is very difficult task for not trained respondent because it is not stable in time (13). Sometimes, especially for FFQ, respondent has to transform information about eaten amount of food into portion size described in the questionnaire. Usually portion size is described in household measures as mug, teaspoon, piece, etc. and respondent does not think in terms of grams, which is needed to assess nutrient intake. That way trained interviewer is very helpful during nutritional recall. We can use different aids to assess the portion size like photographs or models (8, 23).

Validity of the data depends on the time interval between the situation respondent is asked about and time of interview. The longer time span the less accurate information will be available. Some researchers suggest that one can collect information about usual dietary patterns even 15–25 years prior to interview (24), but this information are influenced by the recent diet, life-style changes, etc. The unusual, important situation is recalled in much more details than ordinary habits – the last one can be even averaging (25). It is especially important for nutritional interview – when one is interested in actual not "usual" intake (21, 24, 26).

When we are thinking about assessment of nutrition very important is demographic characteristics of the person and his/her knowledge about food and nutrition, and personal experience in food preparation (27, 28). Respondents, who are personally responsible for food preparation, are more reliable in giving information about products and describe eaten portion size more precisely than others. On average, men more likely than women report bigger portion size and then report higher amount of energy (29, 30). The other factor that influences validity of nutritional data is respondent's age. Generally, there are no significant differences across age group of 18–64 years olds. Outside this age range, factors such as memory or conceptualization skills may have important impact on validity of results.

Tooze et al. (31) showed four areas dependent on respondent, which can influence the validity and reliability of estimates (Fig. 6.1). They are: psychosocial factors, life-style, skills and knowledge, and diet characteristics. Indirectly, one can observe impact of gender, age and education level on each of these areas.

Assessment of energy and nutrient intake from diet in the epidemiologic studies is mainly based on calculation using food composition tables. Unfortunately, such tables contain information only about chosen foods and dishes (32). The same dish prepared in the different households may vary with respect to energy and nutrients content. So using food composition tables is an additional and very important source of error in dietary assessment.

Roszkowski et al. (8) showed the important role of coding system for data transformation in the assessment of nutrient intake. The authors compared the same 47 individual recalls analyzed in eight centers in Poland to estimate the amounts of energy and nutrients intake. They found that variability of assessment ranged from 9.9% up to 77.0% – the lowest variability (between centers) was observed for animal protein intake (56.6 – 68.9 g), the highest for calcium (824 – 1753 mg).

Every method has its own pros and cons. Table 6.1 shows the most frequent errors connected with different interview/recall methods in nutritional epidemiology. The method, used in the research for the first time or in the population different from population it was designed for, should be validated before using it in the main research (1, 2). The most frequently used instrument for the reference is multiple 24-hour recall or diary. It is also possible to use biomarkers of energy intake (e.g., DLW = doubly labeled water (33)) or particular nutrients (16, 34, 35).

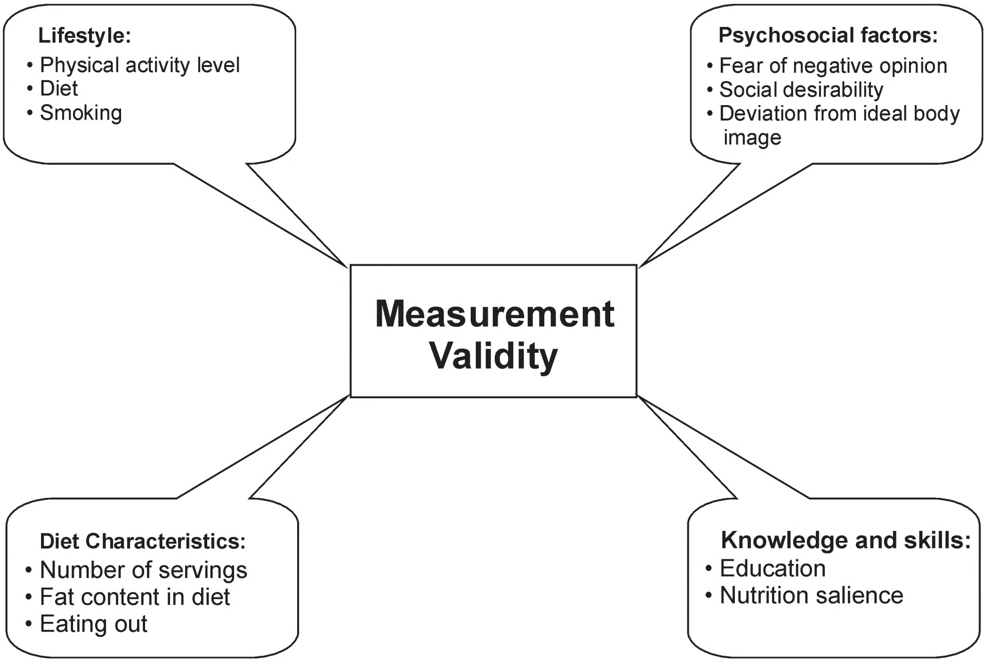


Figure 6.1. Factors affecting the validity of nutritional data

Table 6.1. Sources of errors in different methods of nutrition assessment

| Sources of error | Nutrition assessment method | | | | |
|---|---|---|---|---|---|
| | Dairy | 24-hour recall | 7-day record | Diet History | FFQ |
| Omission/addition | + | + | ++ | +++ | ++ |
| Mass or volume estimation | + | ++ | ++ | +++ | – |
| Assessment of frequency | – | – | + | +++ | + |

+++ very high possibility of error
++ high possibility of error
+ low possibility of error
– method does not allow for this type of assessment

## Adjustment for energy intake in epidemiologic analyses

When relation between diet and disease is analyzed nutritional factors can be examined in terms of absolute intake or in relation to total energy intake. The analytic model depends on the nature of biologic relationship and the public health considerations. If the nutrient is metabolized in approximate proportion to total caloric intake (macronutrients, some vitamins) the nutrient intake is most biologically important in relation to energy intake. If nutrient selectively affects an organ system that is uncorrelated with body size or if physical activity doesn't reflect the nutrient metabolism absolute intake should be most relevant. There are several methods to adjust the intake for total energy intake (1, 2):

1. *Nutrient Density* – that is a measure of dietary composition calculated by dividing nutrient values by total caloric intake. Sometimes, for macronutrients, it is expressed as percentage of total energy from specific macronutrient. When energy intake is unrelated to the disease calculation of nutrient density may reduce variation in nutrient intake that is due to differences in body size, activity and metabolic efficiency. In situation when a specific nutrient has a week correlation with the total energy dividing by total caloric intake creates variable that is in fact highly related to the total energy intake – and our aim was to avoid this relation.
2. *Residual Method* – energy-adjusted nutrient intake is computed as residuals from the regression model with total caloric intake as an independent variable and absolute nutrient intake as dependent variable. The nutrient residuals provide a nutrient intake uncorrelated with total energy intake. Because residuals have mean of zero and allow for negative values they do not provide any intuitive sense of actual nutrient intake. So sometimes it is desirable to add the constant to residual value – most frequently predicted nutrient intake for the mean intake of energy (from the statistical model).
3. *The Standard Multivariable Method* – this approach is to include both total energy intake and absolute nutrient intake as independent variables in a multiple regression model with disease outcome as a dependent variable. This model creates complexities in interpretation of results. The regression coefficient for calories represents calories intake independent of the specific nutrient. For example, if our nutrient of interest is fat – the regression coefficient for energy represents intake of protein, carbohydrates and alcohol. So including the specific nutrient in one model together with total caloric intake can change the biologic meaning of energy intake (like in the example).
4. *"Energy Decomposition" Method* – in this model energy is separated in two part – the first one – from the specific nutrient, and the second one – from other sources – and both terms are included in the model.
5. *Multivariable Nutrient Density Model* – in this model nutrient density and total energy intake play as independent variables.

   The formulas for each described statistical regression model one can find in Table 6.2.

Table 6.2. Different disease risk models for addressing the correlation of specific nutrient with total energy intake

| **Model** | **Formula** |
|---|---|
| Nutrient Density Method | Disease = b * Nutrient Density |
| Residual Method | Disease = b * Nutrient Residual |
| Standard Multivariable Method | Disease = $b_1$ * Nutrient + $b_2$ * Energy |
| "Energy Decomposition" Method | Disease = $b_1$ * Energy $_{\text{Nutrient}}$ + $b_2$ * Energy $_{\text{Others}}$ |
| Multivariable Nutrient Density Model | Disease = $b_1$ * Nutrient Density+ $b_2$ * Energy |

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